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A BROADBAND ACCELERATOR CONTROL NETWORK*

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Summary

A broadband data communications network has been implemented at BNL for control of the Alternating Gradient Synchrotron (AGS) proton accelerator, using commercial CATV hardware, dual coaxial cables as the communications medium, and spanning 2.0 km. A 4 MHz bandwidth Digital Control Channel using CSMA-CA protocol is provided for digital-data transmission, with 8 access nodes available over the length of the RELWAY. Each node consists of an rf modem and a microprocessor-based store-and-forward message handler which interfaces the RELWAY to a branch line implemented in GPIB. A gateway to the RELWAY control channel for the (preexisting) AGS Computerized Accelerator Operating System has been constructed using an LSI-11/23 microprocessor as a device in a GPIB branch line. A multilayer communications protocol has been defined for the Digital Control Channel, based on the ISO Open Systems Interconnect layered model, and a RELWAY Device Language defined as the required universal language for device control on this channel.

Introduction

Particle accelerators exhibit a voracious appetite for communications bandwidth, both digital and analog, for device control and for instrumentation. This need parallels the developing commercial market for local area networks (LAN). However, the physical extent of large accelerators precludes use of most commercially offered LAN's, as also does the baseband nature of most commercially available LAN's, which offers inadequate bandwidth for accelerator application. Recognition of this communication need for the CBA (Colliding Beam Accelerator) Project at BNL prompted development of a broadband communications network suitable for use in an accelerator environment. The increased demands which the Polarized Proton Project will make of the AGS control system have prompted installation of this network, dubbed RELWAY (for RELiable data highWAY), at the AGS and interfacing it with the existing AGS control system.

Network Components

The installed network contains the following components (Fig. 1): (A) dual coaxial cable linking all sites on the network; (B) passive directional couplers: (C) "Comboxes" containing rf modems which modulate/demodulate baseband signals into the broadband network, and microprocessor-based store-and-forward message handlers for the digital control channel; (D) the GPIB (General Purpose Interface Bus, or IEEE standard 488), linking a combox to a "station" on the control channel; (E) "stations" which support the communications protocol on the Digital Control Channel; (F) controllers for accelerator hardware; (G) a "gateway" interfacing the network control channel protocol to that of the host processor; and (H) time-sharing "host" computer for accelerator operations.

The cable is a broadband component. The other components support only one channel, or baseband, on the network. Not shown is use of the network for analog signal transmission (such as voice communication or timing signals) by rf modulation into a selected channel with injection via directional couplers.

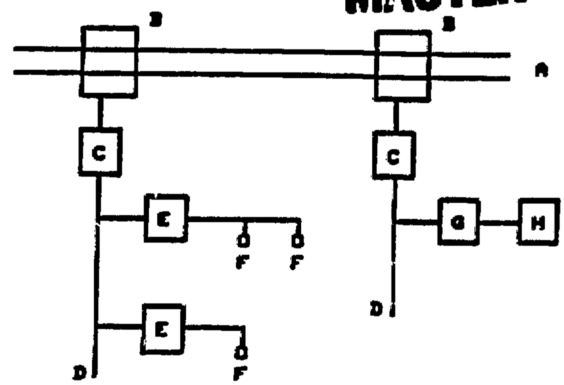

Fig. 1. RELWAY Components
(A) Dual coaxial cable; (B) directional couplers; (C) Combox; (D) GPIB; (E) Station; (F) Accelerator hardware controllers; (G) Gateway PP; (H) Host Computer

RELWAY

The communications medium in RELWAY is a pair of high bandwidth low loss coaxial cables. Each cable carries signals propagating in only one direction. Passive directional couplers permit nodes on the network to transmit and receive rf signals to/from the correct direction on each cable (Fig. 2). The cable and couplers are standard CATV commercial items offering low cost and high reliability. An option available for future expansion is insertion of high reliability CATV line amplifiers as increasing network length and number of nodes may require. The cable route includes the Linac, most of the AGS ring, the control building, the RF/MG building, the "slow extracted beam" experimental hall, and a portion of the "fast extracted beam" line.

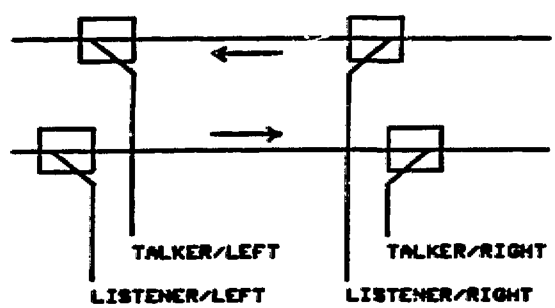

Fig. 2. Directional Couplers

Analog Channels

Several channels have been targeted for analog use. One or several channels will be used to transmit standard timing signals around the AGS. Another channel has been used to implement a voice communication

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link by the simple expedient of using CB radio gear.

Combox

The Digital Control Channel is coupled to the network through a "combox", which contains an rf modem and an 8085-based microprocessor. The microprocessor accepts messages from the cable on the control channel for retransmission on a GPIB to a receiver "station", and accepts messages from local stations on the GPIB for retransmission on the cable to their ultimate destination. These messages are handled on a store-and-forward basis, the combox thus solving the problem of gaining access to the cable for all its local stations. The combox is always controller of the GPIB, and the stations only talker/listeners.

CSMA-CA Protocol

The "contention" of multiple comboxes for simultaneous access to the control channel is resolved by use of a CSMA-CA protocol (Carrier Sense Multiple Access-Collision Avoidance). Before transmitting, a combox ensures (by monitoring its "receive" lines) that no other combox is transmitting. The combox then transmits carrier, while continuing to monitor its "receive" lines, for a period long enough to ensure that its signal has propagated to all nodes on the network; following that, data transmission begins and continues to completion of the message. Propagation delays may enable two comboxes "simultaneously" to see a clear channel, permitting both to begin to transmit carrier. This condition is termed a "collision"; both comboxes will observe the collision since they are monitoring their "receive" lines. When a collision occurs, one combox will defer, i.e., stop transmitting; priority in this matter is determined by position on the bus. Any desired node on the network can be selected to be the highest priority node. The CSMA-CA protocol guarantees that no collision will occur once data transmission has begun. Immense simplification is achieved in collision detection by the use of two coaxial cables and directional couplers, since a combox's own carrier is not present on its "receive" lines.

Host

The host computer of the AGS control system is a PDP-10 running a modified version of the manufacturer's standard operating system TOPS-10. Present accelerator hardware is controlled over high speed (0.5 Mbaud) half-duplex serial data links called Datacon; the Datacon lines are controlled by a network of five PDP-8 peripheral processors (PP). The PP's are connected to the host PDP-10 by full duplex high speed (0.5 Mbaud) serial data links; host communications with the PP's are supported by a monitor level protocol in the host.[1] Host-PP communications are structured in the form of file transfers. User programs construct files to send to the appropriate PP's; these files contain instructions to the PP's to perform transactions on the Datacon lines. Resulting data obtained by the PP's from accelerator devices over the Datacon lines are assembled into files which can be received by user programs from the PP's.

A subset of the Host-PP file-structured communications protocol has been utilized, almost unchanged, to support communications between the host and a new Gateway PP which provides access to the RELWAY. An additional full duplex high speed serial link has been installed to connect the host to the Gateway PP.

Gateway PP

A Gateway PP has been implemented using an LSI-11/23 running the RSX-11/S operating system. An interface is provided for the high speed serial link to the host, and a DMA interface is provided to make the 11/23 a talker/listener device on the GPIB. Both of these devices are supported by RSX system drivers. A user task running in the Gateway PP converts the Host-PP communications protocol into the RELWAY protocol, off-loading that task from the host. The Gateway PP receives host-bound transmissions from the RELWAY, packages them in a file structure acceptable to the host, and queues these files for transmission to the host as the host shall request them.

Station

RELWAY stations are constructed from Intel board-level 16-bit multibus microprocessor products, running the RMX-88 operating system. These stations are talker/listeners on the GPIB controlled by the RELWAY combox. A standard software package for these stations is embedded in PROM and will support all stations currently envisioned. The station software supports the communications protocol defined for the RELWAY, and performs operations on accelerator hardware under its control according to RELWAY messages it receives. Two forms of station communication with accelerator hardware are currently defined, each supported by station software drivers. The first form consists of hardware on a local GPIB (distinct from the combox GPIB) for which the station is controller. The second form consists of hardware controlled by another multibus processor, with which the station processor communicates via shared multibus memory.

The first generation of station software supports three categories of operations. (1) Stations can set hardware to specified states and setpoints. (2) Stations can acquire readbacks from hardware on each AGS cycle and report these readbacks via RELWAY to the requester. This operation is referred to as the report task. As a practical matter, the requester is always the host PDP-10 computer via the Gateway PP; however, the RELWAY protocols do not assume this relationship and will support a different host or even multiple host computers. (3) Stations can acquire readbacks from hardware on each AGS cycle and compare the readbacks with standard values provided by the host, and report deviations from expected values to the host on an exception basis. This operation is referred to as the alarm task.

Relway Communication Protocols

The communication protocols defined for the Digital Control Channel on the RELWAY constitute a layered protocol based in spirit upon the International Standards Organization (ISO) Open System Interconnect (OSI) seven layer model.[2] The protocol will be implemented in a staged fashion. The comboxes implement layers 1 and 2 of the ISO/OSI model. The remaining layers are implemented in the Host/Gateway and in the stations. Layers 3, 4, and 5 are supported at the operating system level, layers 6 and 7 at the user code level. Gateway support for the lower levels of the protocol frees the programmer in the Host from concern about these levels. The Host programmer need only respect the protocol at levels 6 and 7, which constitute the "RELWAY Device Language", which all stations will recognize, and the details of the physical devices under control of the host program. The Gateway software will be insensitive to details of the RELWAY Device Language.

System Advantages

The broadband nature of the RELWAY makes it possible to support multiple noninterfering Digital Control Channels, each dedicated to a particular accelerator subsystem and controlled, if necessary, by a separate host. Each such channel requires a Gateway (not necessarily distinct), a combox and directional couplers.

The fact that the Relway network is democratic (vs master-slave) gives rise to several significant advantages. It permits use of asynchronous messages, especially alarms, rather than polling. It permits easy implementation of a multihost system, providing an easy evolutionary path for control system development. It also allows the development of more elegant control system structures which provide for communication (and thus cooperation) between stations, without the necessity of passing messages through the host computer. The network could also be used as a communications medium between host computers.

In the large context, the RELWAY permits the viewpoint that the Digital Control Channel is simply a GPIB of great physical extent and with extended addressing capability. As such, the Digital Control Channel enjoys all the advantages of the GPIB, especially including great versatility in message format and content (as compared to the previously used Datacon system). The stricture that the RELWAY be implemented on a single physical cable imposes a certain rigor on the physical layout of the control system, but confers the advantage that comes with a unified communication system.

Operating Experience and Schedules

The physical cable has been in place for about six months, and extensive testing of digital communications between the control building and the Linac node slated for source control have demonstrated the reliability of the system; frequency spectrum analysis of the cable during accelerator operation indicates no interference with communications is to be expected. The Gateway processor has been commissioned; Gateway software has been designed and is at an advanced stage of coding. Communications between the Host and the Gateway have been tested and verified. Station software is in the design stage, with coding nearly ready to begin. Stations slated for immediate implementation include: (1) control of the ion source, the RFQ, and the Low-Energy Beam Transport Line; (2) interface to Linac instrumentation, including the 200 MeV Polarimeter; (3) interface to the Ring Polarimeter for AGS circulating beam; (4) interface to the Ionization Profile Monitor for AGS beam profile measurements. These stations should be on-line by September 1983. Stations for control of the Fast Pulsed Quadrupole system for polarization control across intrinsic resonances, and control of the Fast Pulsed Dipole system for polarization control across imperfection resonances (pulsing 96 dipoles up to 64 times per AGS cycle) should be in place by January 1984.

References

1. M.Q. Barton, et al. Proc. IXth Intern. Conf. on High Energy Accelerators, SLAC, p. 495 (1974).

2. R. desJardins and G.W. White, Proc. Trends and Applications: 1980 Computer Network Protocols IEEE 80CH1529-7C, p. 47 (1980).

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